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ELECTRON DENSITY FLUCTUATIONS
IN THE IONIZATION ZONES OF AURORAE

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ELECTRON DENSITY FLUCTUATIONS
IN THE IONIZATION ZONES OF AURORAE

(Fluktuatsii elektronnoy plotnosti v zonakh
ionizatsii polyarnykh siyaniy)

Geomagnetizm i Aeronomiya
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by V. I. Pogorelov

ABSTRACT.

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Computed is the mean-square value of fluctuations of electron concentration in the zones of formation of ultra-short wave reflections during aurorae.

The estimate made as a result of experimental data analysis from the standpoint of diffusion theory leads to absolute values of fluctuations reaching 10^5 electron/cm³.

COVER TO COVER TRANSLATION

Author

The value of mean-square fluctuations of electron concentration constitutes one of the most important parameters of ionization zones appearing near the aurora regions. It may be estimated thanks to the scattering effect of radiowaves at radar sounding of these zones. In the general case, the effective scattering cross-section, corresponding to the unitary element of medium's volume, will be determined by the directions of wave vectors of the incident and scattering waves, as well as by that of the outer magnetic field vector in the region of scattering. Thus, basing ourselves upon the general postulates of the theory first brought forth by Booker and Gordon in 1950, and developed in references [1 - 3] for regions, where the stationary magnetic field component is orthogonal to the

to the wave vector of the primary emission (region of the maximum scattering in the reverse direction), one may represent the effective scattering cross section by the unitary medium volume in the form

$$\sigma = k(\lambda) \overline{(\Delta N)^2},$$

where λ is the length of radiowaves; $\overline{(\Delta N)^2}$ is the mean value of the square of fluctuation of electron concentration.

The expression $k(\lambda)$ depends upon the form of the correlation function, which cannot be determined universally and quite precisely. That is why, we shall conduct, as this is often done, two parallel estimates for the cases of realization of correlation functions of the types

$$\exp \left\{ - \sum_{i=1}^3 \frac{x_i^2}{2L_i^2} \right\}, \exp \left\{ - \left(\sum_{i=1}^3 \frac{x_i^2}{L_i^2} \right)^{1/2} \right\},$$

where x_i are difference in the coordinates of the compared points; L_i are constants, determining the dimensions of ionization inhomogeneities in the direction of the coordinates x_i [1]; (these constants are different for various i by the strength of anisotropy of electron concentration distribution).

Basing ourselves on the results expounded in [4, 5], it is easy to obtain, that the effective scattering cross section of waves λ by one cubic meter of the medium per solid angle unit, which can be achieved in reality in the reverse and perpendicular direction to the stationary component of the magnetic field, will be equal to

$$\overline{\sigma}_1 = 1,2 \cdot 10^{-28} \overline{(\Delta N)^2} T^2 L \frac{\exp \{ -8\pi^2 T^2 / \lambda^2 \}}{\sqrt{1 + 0,13 L^2 \lambda^{-2}}} \quad (1)$$

in case of the realization of the first and in case of the second of the above- indicated correlation functions.

$$\overline{\sigma}_2 = 3,1 \cdot 10^{-28} \frac{\overline{(\Delta N)^2} T^2 L}{(1 + 16\pi^2 T^2 \lambda^{-2})} z^{1/2} e^{-z/2} W_{-\frac{3}{4}, -\frac{3}{4}}(z). \quad (1a)$$

Here $W_{-\frac{3}{4}, -\frac{3}{4}}$ is the Whittaker function; $z = 4(\lambda^2 + 16\pi^2 T^2)/L^2$; T and L are respectively the values of L_1 for a perpendicular and a parallel directions to the magnetic field. As shown in [4], they must be taken equal to about 0.1 and 30 meters.

Inasmuch as in the following we examine the reflections originating only from the region where they are most intense, i.e. where $\bar{\sigma}$ is little different from its maximum value, the power ratio of the received in reverse (reflected) to the emitted signal must be approximately equal to the product of the above-introduced quantities $\bar{\sigma}_{1,2}$ by the space volume, whose scattering is registered by the locator. The dimensions of the given volume lend themselves perfectly to an estimate.

As is well known, the radial thickness of the volume determining the power of the signal scattered in the reverse direction, is $\tau c/2$, where τ is the duration of the sounding pulse.

Informations about the other two volume dimensions searched for provide measurements carried out at a series of research stations. As follows from [4, 6], the dimension parallel to the azimuthal plane is of the order of 200 km, provided the radiation pattern of the utilized antenna is sufficiently broad to encompass the given region.

According to [7-9], the third dimension, the thickness of the basic layer of sporadic ionization at aurorae, is approximately equal to 3 km. Consequently, the magnitude of the volume of the region where the scattered emission originates and reaches the locator at a specific moment of time, is equal to about $3 \cdot 10^8 \tau c$ m². The density of the energy flux of the scattered emission at the point of radar location will be equal to

$$3 \cdot 10^8 \frac{g^2 p \tau c}{(4\pi)^2 r^4} \text{ w/m}^2$$

and the power of the received signal

$$p_1 = 3 \cdot 10^8 \frac{g^2 \lambda^2 p \tau c}{(4\pi)^2 r^4},$$

whence

$$\frac{p_1}{p} = 90 \cdot 10^{16} \frac{g^2 \lambda^2 \tau}{(4\pi)^3 r^4}, \quad (2)$$

where p is the power of radar emission in the pulse; g — the antenna amplification factor, average for the angular coordinates of the points of scattering volume; r is the distance to the considered scattering region.

The quantity p_1/p is easily determined by experimental observation results. According to measurements at Roshchino (60° , 2° N, 29.6° E), it mostly oscillates within the limits of values $(1 \div 6) \cdot 10^{-18}$ for $r = 7 \cdot 10^5$ m, $g = 30$, $\tau = 10^{-5}$ sec., $\lambda = 4$ m.

Taking this into account, we find from the equations (1), (1 a), (2) the magnitude of the mean-square value of electron density fluctuations

$$\begin{aligned} \sqrt{(\overline{\Delta N})_1^2} &= (6 \div 15) \cdot 10^4, \\ \sqrt{(\overline{\Delta N})_2^2} &= (4 \div 10) \cdot 10^4 \text{ el/cm}^3 \end{aligned}$$

respectively for the first and second forms of the correlation function.

Let us compare the result obtained with some other estimates available in literature. The most complete data are included in the review [10], where this question is dealt with in great detail.

As is well known, Booker [1] determined $(\overline{\Delta N/N})^2 = 10^{-7} \div 10^{-6}$ (which for the electron concentration mean value he admitted — $N = 10^6 \text{ cm}^{-3}$ corresponded to $\sqrt{(\overline{\Delta N})^2} \sim 3 \cdot 10^2 \div 10^3$). The given quantity which was derived at assumptions later resulting unfounded, was evidently underrated. This followed for instance from the work by Al'pert [2], published at about the same time as [1], where he arrived at $(\overline{\Delta N/N})^2$ of the order of $10^{-4} \div 10^{-3}$, having independently conducted a similar theoretical analysis, but applied to the quiet ionosphere. It is obvious that the value obtained by Booker must be greater rather than smaller than that obtained by Al'pert.

The latest estimate made by Nichols [11], on the basis of character investigation of radiowave absorption in the ionization regions of aurorae, also led to a notable greater value of $(\overline{\Delta N}/N)$, lying within the limits from 10^{-4} to 10^{-2} . This agrees well with the results presented here, if, according to latest measurements [12], a value $N \approx 3 \cdot 10^6$ electron/cm³ is taken for electron concentration in the aurora regions (E_{au}). That is why preference is given to Nichols estimate from the standpoint of the present work, by the authors of reference [5], rather than to Booker's estimates based on the analysis of the scattering effect of radiowaves. But generally speaking, there are apparently no causes of any sort, instrumental in making errors at determination of electron concentration in the ionization zones of aurorae by methods of diffusion theory.

Let us note that the accounting for magnetic field fluctuations, discussed in detail in [4], plays no decisive part in the above-described results, inasmuch as the ratio of estimates made with this accounting and without it, is of the order of 1.7.

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***** E N D *****

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